

SYSTEM AND METHOD FOR EFFECTIVE YIELD LOSS ANALYSIS FOR SEMICONDUCTOR WAFERS

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BACKGROUND OF THE INVENTION

Field of Invention

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[0001] This present invention relates to a defect inspection and classification of semiconductor wafers having a plurality of dies. And more particularly, the present invention relates to a method for calculating yield impact contributed by specific defect type in order to predict yield loss effectively.

Description of Related Art

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[0002] Defect monitor methodology typically involves defect inspection and classification of defect types through optical microscope and Scanning Electron Microscope (SEM) review in order to control particles and defects that are inexpectant in production.

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In order to shorten the respond time and implement appropriate improvements for integrated circuits manufacturers, it is fairly important to establish an estimation scheme of various types of defects on the yield issue. This estimation scheme also allows an engineer to prioritize the defect reduction plan in the fabrication process. The first literature for yield estimation was reported by Wallmark in 1960. Since then, extensive work has been done concerning the different defect density distribution and probability function. However, the methodology for computing the effect of defects on yield was not well developed.

[0003] Defect counts are usually used to track excursions and set priorities for defect

reduction efforts, but the total defect counts information on its own or even including further characterizations for each single defect by optical microscopes or SEM is not sufficient to control excursion. Moreover, it is neither sufficient to assign an accurate number of yield loss according to the existing yield prediction models to each process for complex chip designs. The review of all inspected defects may as well delay the manufacturing process of semiconductor chips and yield learning cycles significantly.

[0004] The concept of “kill ratio” is introduced to estimate the effect of defects on yield loss contributed by specific defect type. It can be defined as the upper limit for yield estimation that could be obtained if the defect type was the only factor affecting the yield.

An available prior methodology provides a method following the steps:

[0005] (a) The step of computing kill ratio for a given process inspection includes dividing hits on failed dies by defect counts for the process inspection may be included.

[0006] (b) The step of determining a number of dies to be killed by considering kill ratio for the dies with hits to weight the defects of each die. It may include the steps of determining a number of dies to be killed by considering all dies with hits, initializing the number of dies to be killed to zero, and modifying the number of dies to be killed. This modification can be done by calculating a kill ratio between a kill ratio for each process inspection having hits and a sum of the kill rates for all process inspections having hits and adding the ratio to a previous number of dies to be killed. The previous number of dies to be killed is being obtained at a previously considered die and repeating the step of modifying until all dies have been considered.

[0007] (c) The step of the foregoing modification is preferably performed using the formula:

$$k_i = k_{i,previous} + m \cdot \frac{r_i}{\sum_{i=1}^n r_i}$$

where k_i is a newly calculated number of dies to be killed for inspection process i , $k_{i,previous}$ is the previously calculated number of dies to be killed for the defects of inspection process i , r_i is the kill rate for a given inspection process i , n is the number of processes which provided hits to the dies to be killed and m is the defect counts of a give type for a die being considered for the inspection process i .

[0008] (d) The step of determining a yield loss for each inspection process based on the number of dies to be killed and a total number of dies may include calculating the yield loss by dividing the number of dies to be killed of a given inspection process by the total number of dies of the semiconductor wafer. The method may further include the step of determining a killing probability yield loss for each inspection process based on the number of dies to be killed for each inspection process and a total number of defects for the inspection process.

[0009] Unfortunately, practitioners in the semiconductor industry still hazily utilize the kill ratio concept. To obtain useful yield impact information, it is desirable to establish a succinct “kill ratio” definition in order to filter out excursions in control table, and show an effective expression for yield loss contribution for specific defect type.

SUMMARY OF THE INVENTION

[0010] It is an object of the present invention to provide a calibrated method to calculate kill ratio upon inspected real defect counts of a semiconductor wafer having a plurality of dies.

[0011] It is an object of the present invention to provide a calibrated method to calculate kill ratio upon sampled defect counts of semiconductor wafer having a plurality of dies.

[0012] It is an object of the present invention to provide a method to predict yield loss with respect to yield impact upon selected defect density function according to defect classification on certain layer of a semiconductor wafer having a plurality of dies.

[0013] As embodied and broadly described herein, the invention provides a method to accomplish above objects, including the following steps:

[0014] (a) The step of computing kill ratio for a given process inspection includes dividing a number of hits on failed dies by a number of defects of wafer for the process inspected.

[0015] (b) The step of determining a number of yield impact contribution by considering defect counts of a specific defects for all die with hits to weight the hit ratio of each defect, includes the steps of initializing the yield impact contribution of specific defect to zero, and modifying the yield impact contribution number. This modification can be done by calculating a hit ratio weighted by defect counts of specific defect for each die inspection having hits and a sum of the weighted hit ratio for all defect inspections having hits and adding the ratio to a previous yield impact contribution. The previous yield impact is being obtained at a previously considered die and repeating the step of modifying until all dies have been considered.

[0016] (c) The step of modifying is preferably performed using a formula:

$$Kc_{ij} = Kc_{ij-1} + \frac{hr_i \cdot n_{ij}}{\sum_k (hr_k \cdot n_{kj})} \cdot \varphi_i \quad \text{EQ. 1}$$

where

Kc_i : the yield impact contributions of a specific defect i

j : die index (from 1 to N)

k : defect index

hr_k : hit ratio of a specific defect k

n_{kj} : the specific defect k count of die j

5 φ_j : die impact factor of die j ;

The yield impact is then calibrated with the formula:

$$Kc_i = Kc_{ij} \cdot \alpha \quad \text{EQ. 2}$$

where α is a defect contribution calibrated factor

[0017] (d) Furthermore, to establish a more effective yield model, defect inspection
 10 following “die-based sampling” is introduced in order to expedite kill ratio estimation.
 In replacement with foregoing Kc_i , the step is preferably performed using a formula
 following foregoing naming convention:

$$Kc_i = K'c_i \cdot \alpha \quad \text{EQ. 3}$$

$$K'c_i = \frac{hr_i \cdot \omega_i}{\sum_k (hr_k \cdot \omega_k)} \cdot n_f \quad \text{EQ. 4}$$

15 where

k : defect code

n_f : fail die count with defect

hr_k : hit ratio of specific defect k

ω_k : the percentage of specific defect k of defect review sampling

20 [0018] (e) The step of calculating kill ratio upon yield impact factor Kc_i is preferably
 performed using the formula:

$$Kr_{i0} = \frac{Kc_i}{(ND_{i0}A)\beta_i} \quad \text{EQ. 5}$$

where

Kr_{i0} : the average kill ratio that a specific defect i kills a die

D_{i0} : average defect density of specific defect i

A : die area

5 β_i : average defect density of specific defect i vs. yield impact contribution
calibrated factor

[0019] (f) Lastly the step of yield loss prediction is preferably performed using the
formula:

$$Y_i = Kr_{i0} \cdot [(D_{i0}A)\beta_i] \quad \text{EQ. 6}$$

10 [0020] It is to be understood that both the foregoing general description and the follow-
ing detailed description are exemplary, and are intended to provide further explanation
of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

15 [0021] The accompanying drawings are included to provide a further understanding of
the invention, and are incorporated in and constitute a part of this specification. The
drawings illustrate embodiments of the invention and, together with the description, ser-
ve to explain the principles of the invention.

[0022] FIG. 1 is a flow/block diagram showing a method for determining yield loss in
20 accordance with one preferred embodiment of this invention.

[0023] FIGS. 2a-2b form a flow/block diagram showing a method for determining yield
loss upon real defect counts in accordance with one preferred embodiment of this in-
vention.

[0024] FIGS. 3 and 2b form a flow/block diagram showing a method for determining yield loss upon die-based-sampling defect counts in accordance with one preferred embodiment of this invention.

[0025] FIG. 4 illustrates a set of 44 dies having two types of defects followed by real classification analysis for inspected defects on a wafer in accordance with one preferred embodiment of this invention.

[0026] FIG. 5 illustrates a set of 44 dies having two types of defects followed by sampling classification analysis for inspected effects on a wafer in accordance with one preferred embodiment of this invention.

[0027] FIG. 6 is a table of choices of defect density functions for yield loss calculation in one preferred embodiment of this invention.

[0028] FIG. 7 is a table of data and a chart showing yield loss upon various yield models in accordance with one preferred embodiment of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0029] This disclosure relates to a yield loss analysis method of semiconductor wafers having a plurality of dies, and more particularly to a method for estimation of yield impact contributed by specific defect in order to predict yield loss. The present invention provides a method for “kill ratio” calculation according to defect counts for each defect type and die of a wafer. The present invention also provides a method for effective “kill ratio” calculation with the participation of defect contribution calibrated factor upon “die-based-sampling” technique. Lastly, the present invention provides a method de-

termining yield loss upon selected defect density distribution model. The yield loss analysis method is described as follows.

[0030] Referring now in specific detail to the drawings in which like reference numerals identify similar or identical elements throughout the several views. Initially referring to

5 FIG. 1, a flow/block diagram 100 is shown. In block 101, defects are reviewed by automated optical microscope or manual scanning electron microscope (SEM) to determine defect counts for specific types of defects of dies of a wafer. The inspection can be extended to classification of defects of dies, or of layers of wafers in different lots of semiconductor processes. In block 102, hit ratio of each inspected defect type is calculated

10 by the method of dividing an impacted die counts by the defect counts of a specific defect type of a wafer. Yield impact of the specific defect type is also calculated with the weighted hit ratio divided by the sum of weighted hit ratio of each defect type, with the participation of an impact calibrated factor. In block 103, a yield impact calibrated factor is calculated upon choice of defect density distribution functions provided in the table in FIG. 6. In block 104, kill ratio for the specific defect type is obtained by the calculation of dividing the yield impact by a product of average defect density of the specific defect and the specific defect counts. Lastly, in block 105 the yield loss of the inspected wafers having a plurality of dies is obtained therein by multiplication of average kill ratio, defect counts and yield impact contribution calibrated factor.

20 [0031] Referring to FIG. 2a-b, a flow/block diagram is shown. A method for yield loss analysis in accordance with real defect classification is described therein. The preferred embodiment of this method in FIG. 4 is simultaneously demonstrated. In block 201, the hit ratio of a specific defect type is determined upon dividing the impacted fail die

counts by the inspected defects counts of wafer. Real defect counts of inspected defect types are used therein. Referring to FIG. 4, providing a wafer having a plurality of 44 dies, two types of defect are inspected therein. The defect count of type ® is 85, and the defect count of type © is 30. Among 10 failed dies, 8 dies of each type are found hit and failed for both types of defect. Thus the hit rate for the present types of defect is obtained: $hr_{®} = 8/85 = 0.094$, $hr_{©} = 8/30 = 0.267$. In block 202, in order to eliminate the excursion of defect counts between a plurality of defect types and dies, a defect contribution calibrated factor is introduced therein. Considering pass/fail events, and with/without defect dies, the defect contribution calibrated factor is defined by a plurality of parameters herein:

$$\alpha = \left[1 - \frac{a/b}{c/d} \right] \cdot \frac{b}{b-a}$$

where

a = pass die count with defect

b = total die count with defect

c = pass die count without defect

d = total die count without defect

[0032] In this present embodiment, α is calculated: $\alpha = \{1 - [(25 / 36) / (7 / 8)]\} * [36 / (36 - 25)] = 0.675$. Notice that if $\alpha < 0$, the effect of defect is minute, thus can be neglected compared with other parameters of variation. The participation of α mainly estimates the impact of dies with defects instead of using die counts in this present invention.

[0033] In block 203, the yield impact contribution is calculated for each inspected defect type. Utilize the foregoing weighted hit ratio method, formulae EQ. 1-2 demonstrate the calculations:

$$Kc_{ij} = Kc_{ij-1} + \frac{hr_i \cdot n_{ij}}{\sum_k (hr_k \cdot n_{kj})} \cdot \varphi_i \quad \text{EQ. 1}$$

$$Kc_i = Kc_{ij} \cdot \alpha \quad \text{EQ. 2}$$

where Kc_i is the yield impact contribution of a specific defect i , j is die index, k is defect index, α is defect contribution calibrated factor, hr_k is hit ratio of a specific defect k , n_{kj} is the specific defect k count of die j , and φ_j is die impact factor of die j . Notice that $\varphi_j = 0$ when die j is pass die, $\varphi_j = 1$ when die j is fail die. In EQ. 1, Kc_{i0} is preset to zero, i.e.

10 $Kc_{\oplus,0} = 0$, $Kc_{\ominus,0} = 0$. Now referring to block 204. Considering die impact factor φ_j , die 1 to die 32 are all pass die, thus $Kc_{\oplus,j} = 0$ and $Kc_{\ominus,j} = 0$ for $j = 1$ to 32. For defect type \oplus , Kc_{\oplus} starts to accumulate value from die 34, calculated as $Kc_{\oplus,34} = 0 + 1 = 1$. From die 35 on, defect count $n_{\oplus,j}$ starts to play its weighted role to hit ratio and the sum of hit ratio over a plurality of dies, thus the values of $Kc_{\oplus,j}$ for $j = 35$ to 44 are obtained as shown in

15 FIG. 4 sequentially. The values of $Kc_{\oplus,j}$ for $j = 33$ to 44 are obtained under same manner as shown in FIG. 4 in detail. Notice that $Kc_{\oplus,44} = 4.528$, and $Kc_{\ominus,44} = 6.472$ in this preferred embodiment. Consequently, the yield impact for specific type of defect is performed using EQ. 2 with participation of the defect calibrated factor α after all inspected dies are scanned and impact for previous dies are all calculated: $Kc_{\oplus} = 4.528 * 0.675 =$

20 3.056 , $Kc_{\ominus} = 6.472 * 0.675 = 4.369$ in this preferred embodiment shown in FIG. 4.

[0034] In block 205, kill ratio of specific defect of a plurality of dies is calculated. It follows the formula:

$$Kr_{i0} = \frac{Kc_i}{(ND_{i0}A)\beta_i} \quad \text{EQ. 5}$$

where Kr_{i0} is the average kill ratio that a specific defect i kills a die, D_{i0} is average defect density of specific defect i , A is inspected die area, and β_i is yield impact contribution calibrated factor. Notice that β_i is obtained by $\beta_i = f(D_{i0}) / D_{i0}A$, where $f(D_{i0})$ is defect density distribution function varying with defect type and density. The choices of density distribution function are listed in the table in FIG. 6. In this preferred embodiment, $f(D_{i0})$ is chosen to be Poisson model, provided by Hofstein and Heiman as shown in FIG. 6. Kill ratio of types of defect is obtained: $Kr_{\oplus} = 3.056 / 85 = 0.036$, and $Kr_{\odot} = 4.369/30 = 0.146$.

[0035] Lastly referring to block 206, yield loss of each inspected defect type Y_i is calculated upon average kill ratio and yield impact contribution calibrated factor using the formula in EQ. 6:

$$Y_i = Kr_{i0} \cdot [(D_{i0}A)\beta_i] \quad \text{EQ. 6}$$

[0036] Referring to FIG. 3, a flow/block diagram describing an effective method of yield loss estimation is shown. A method of yield loss analysis in accordance with sampled fail die counts is described therein. The preferred embodiment of this method is simultaneously demonstrated in FIG. 5. In block 301, the hit ratio of specific defect is calculated using the formula $h_k = \rho_k / c_k$, where ρ_k is the impacted fail die counts of wafer by the specific defect k upon defect review sampling, and c_k is the specific defect k counts upon defect review sampling. Thus referring to FIG. 5, on the wafer map of this preferred embodiment, those defects that are framed with squares are indicated as those are sampled in this review sampling method. Hit ratio $hr_{\oplus} = 2/5 = 0.133$, and $hr_{\odot} = 3/5 =$

0.6 are calculated therein. Notice that determining hit ratio of each defect type follows the same manner as foregoing embodiment, yet the real impacted fail die counts is replaced with the fail die counts reviewed by a sampling method.

[0037] In block 302, the defect contribution calibrated factor α is calculated by the same manner in foregoing embodiment. Thus α possesses the same value as foregoing preferred embodiment upon real defect counts, where $\alpha = 0.675$. Referring to block 303, a percentage of defect counts ω of a specific defect k over all inspected defects counts is determined. Thus in this preferred embodiment in FIG. 5, 15 of type ® defect are found by sampling, and 5 of type © defect are found as well. Thus $\omega_{®} = 15 / 20 = 0.75$, and $\omega_{©} = 5 / 20 = 0.25$ are obtained as shown.

[0038] Referring to block 304, the yield impact of this preferred embodiment is calculated using the formulae:

$$Kc_i = K'c_i \cdot \alpha \quad \text{EQ. 3}$$

$$K'c_i = \frac{hr_i \cdot \omega_i}{\sum_k (hr_k \cdot \omega_k)} \cdot n_f \quad \text{EQ. 4}$$

where k is defect code, n_f is fail die count, hr_k is hit ratio of specific defect k , and ω_k is the percentage of specific defect k counts out of all inspected defect counts over defect review sampling. Notice that this calculation of yield impact is calibrated with the α factor in the same manner as in the foregoing preferred embodiment, and the weighted hit ratio method in the foregoing preferred embodiment is simplified by weighting with percentage factor ω . The method of sequential calculation through all dies is replaced with a single step for each type of defect. Thus in FIG. 5, $Kc = [(0.133 * 0.75) / (0.133 * 0.75 + 0.6 * 0.25)] * 11 * 0.675 = 2.97$, and $Kc_{©} = [(0.60 * 0.25) / (0.133 * 0.75 + 0.6 * 0.25)] * 11 * 0.675 = 2.97$, and $Kc_{©} = [(0.60 * 0.25) / (0.133 * 0.75 + 0.6 * 0.25)] * 11 * 0.675 = 2.97$.

0.25)] * 11 * 0.675 = 4.455 are obtained therein. Notice that this “die-based-sampling” technique is introduced to expedite the calculation of yield impact K_c , wherein the concept of weighted hit ratio is performed as the percentage of specific defect out of defect review sampling.

5 [0039] The remaining kill ratio calculation and yield loss estimation steps are identical to foregoing preferred embodiment, thus the steps in FIG. 3 are followed by the steps in FIG. 2b thereof, i.e. blocks 205 and 206 concatenate to block 304 thereafter. The values of kill ratio and yield loss are obtained therein: $Kr_{\otimes} = 2.97 / 85 = 0.035$, $Kr_{\odot} = 4.455 / 30 = 0.149$. Notice that the variations between the values of kill ratio herein and those in
10 foregoing preferred embodiments using real defect counts are under 2%, which are appropriate for estimation. To compare the yield loss calculated upon various Seeds and Poisson yield models, a chart is shown in FIG. 7 in accordance with this present invention.

[0040] Having described preferred embodiments for a method for correlating defect
15 counts data to determining kill ratio and yield impact for semiconductor devices, it is noted that modifications and variations can be made by persons skilled in the art in light of above teachings. It is therefore to be understood that changes maybe made in the particular embodiments of the invention disclosed which are within the scope and sprit of the invention as outlined by the appended claims. Having thus described the invention
20 with the details and particularity required by the patent laws, what is claimed and desired protected by Letters Patent is set forth in the appended claims.